Acoustic Communications and Navigation for Mobile Under-Ice Sensors

Lee Freitag
Applied Ocean Physics and Engineering
266 Woods Hole Road, MS#18
Woods Hole Oceanographic Institution
Woods Hole, MA 02543
phone: (508).289.3285 fax: (508) 457.2154 email: lfreitag@whoi.edu
http://acomms.whoi.edu

Award: N00014-12-I-0176 and N00014-12-I-0225 (DURIP)

LONG-TERM GOALS

The long-term goals of this project are to create a new capability for under-ice acoustic navigation and communication, specifically in support of the ONR Marginal Ice Zone (MIZ) Departmental Research Initiative (DRI). The MIZ DRI field program occurred this year, 2014, and the data collected will be analyzed over the next two years. The MIZ DRI includes a large array of sensors deployed on the surface of the ice, as well as Sea Gliders and drifters operating below. The project seeks to answer a number of important science questions, including surface forcing, both mechanical and solar, on the ice and the upper water column. The response of the upper ocean will be established using data collected by the autonomous vehicles operating under the ice, and the data will be assimilated into oceanographic models.

OBJECTIVES

The objectives of the portion of the ONR MIZ project described in this report include development of the under-ice communications and navigation system, plus integration and testing with APL/UW Seagliders and WHOI polar profiling floats during the 2014 deployments in the Beaufort Sea. This system differs from RAFOS and other fixed-beacon navigation systems because the ice-based beacons move, requiring that the location of the source be transmitted. Thus an additional objective was the development of an under-ice digital acoustic communications capability. The communications capability also allows control of the sea gliders using compact commands. The goal for navigation performance was to achieve better than 1 km accuracy at 100 km range, and 100 m at closer ranges (less than 20-50 km). However, as will be seen in the results section, these goals were greatly exceeded.

APPROACH

The system consists of an array of sources suspended from the surface, each equipped with GPS receiver, Iridium terminal and acoustic source. The experiment layout is as shown in Figure 1. The nominal spacing of the navigation sources was 100 km.

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1. REPORT DATE **03 SEP 2014**	2. REPORT TYPE	3. DATES COVERED **00-00-2014 to 00-00-2014**

4. TITLE AND SUBTITLE **Acoustic Communications and Navigation for Mobile Under-Ice Sensors**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Woods Hole Oceanographic Institution,Applied Ocean Physics and Engineering,266 Woods Hole Road,Woods Hole,MA,02543**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Each source operates on a fixed schedule, transmitting 6 times per day, and transmissions are synchronized to GPS time. Each transmission consists of a navigation signal, telemetry with location information, and an optional command. Forty bits are used to convey the current location of an individual source, providing 22 m resolution in latitude and 10 m resolution in longitude at 75 deg N. On the Seagliders and profiling floats a derivative of the WHOI Micro-Modem is used. The platform controller turns on power to the receiver using the fixed transmission schedule. The receiver remains active for the 30-minute period when all of the sources are active, each of which transmits in a 4-minute window. The time base on the remote systems is a SeaScan clock (drift of less than 1 msec/day), and the receiver computes the one-way time-of-flight and its position using multiple range estimates from the different receivers. All of the relevant data is logged by the platform controller and in the case of the glider, used to update its dead-reckoned position.

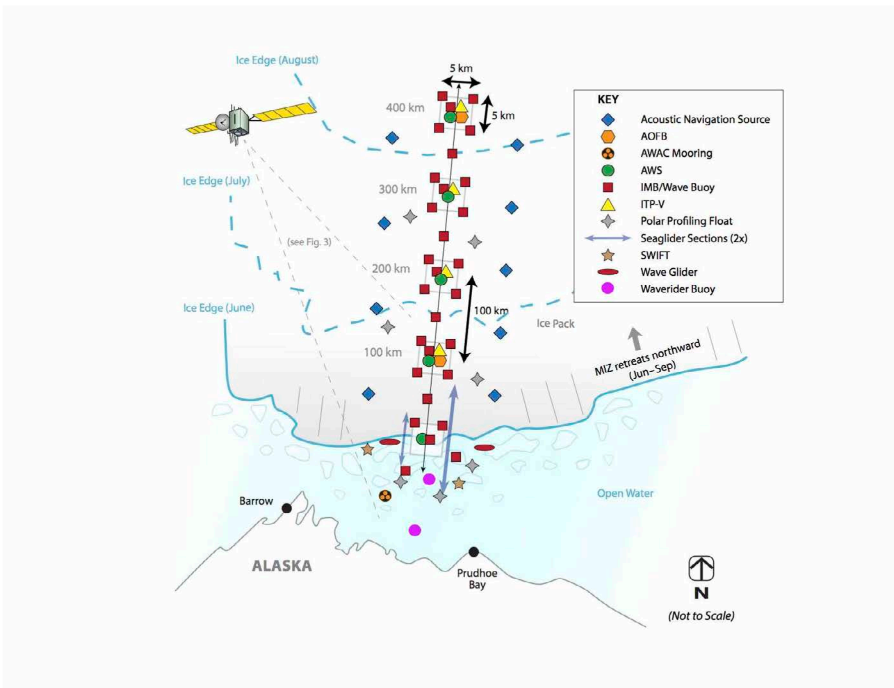

Figure 1. Experimental layout showing navigation sources, ice-tethered profilers, profiling floats and Seagliders. Source spacing is approximately 100 km, and thus 8 sources cover at least 60,000 square km. (Courtesy Lee and Rainville, APL-UW).

WORK COMPLETED

Major work completed in FY 14 included:

1. The GPS-Iridium sub-system was completed and tested on the buoys to confirm proper operation.
2. A control schedule for the buoy transmissions was developed and written and tested through hundreds of cycles.
3. Final assembly of 10 buoys was completed.
4. Receivers for the APL-UW Seagliders and the WHOI Polar Profiling Floats were fabricated and tested.

5. The electronics were tested in an environmental chamber to -40 deg. C to ensure that there were no issues with any of the components or circuit boards.
6. The buoys were shipped to Yellowknife, CA, then assembled there for additional testing outside in the cold, confirming operation of the transmit schedule and the receivers.
7. At Sachs Harbour the buoys were tested again prior to deployment on the ice as part of the MIZ field campaign. Nine were deployed from Sachs Harbor, though one did not function due to a faulty transducer cable.
8. Two additional units were deployed from the ice breaker *Araon* in August, 2014.

Figure 2. Buoy on the ice after deployment from Sachs Harbour, April 2014.

Figure 3. Source being deployed for navigation buoy during Araon-based MIZ operations, August 2014

RESULTS

Source Buoy Design and Construction. The buoy design is new but based on several generations of ITP designs that have been very successful. It consists of a shaped foam collar with aluminum pressure housing with a radome on top to protect the GPS and Iridium antennas, plus a urethane-filled hose with spiral conductors for the through-ice transition where a cable would be vulnerable. The buoy is designed to float after melting out of the ice floe that it is installed on, so that it will continue to provide navigation information in the MIZ, and constructed for easy recovery when drifting. The source is mounted into a cage suspended 100 m below the buoy, and requires a ten-inch diameter hole be drilled in the ice. A 30 kg weight provides a compromise between deployment ease and keeping the cable as vertical as possible when the ice is moving. The buoys are at least partially polar bear resistant because one was knocked on its side during the Fram Strait test in 2013, and it still operated without issues. The deployment of the source directly below holds the buoy upright.

Signal. The beacon transmission includes a frequency-modulated sweep, followed by a short gap, then phase-modulated data with the source location and optionally several bytes of commands or information for the glider. The time of arrival and the source position are provided to the glider after the data are decoded, and the glider uses the source schedule to know what minute the buoy transmitted and compute the one-way travel time. While the transmissions occur every four hours, the interval is programmable and can be changed if necessary depending on requirements and mission length. To avoid interference between the signals from different buoys they transmit in four-minute slots, which allows for approximately 240 km of channel-clearing time because the signal lasts approximately one minute.

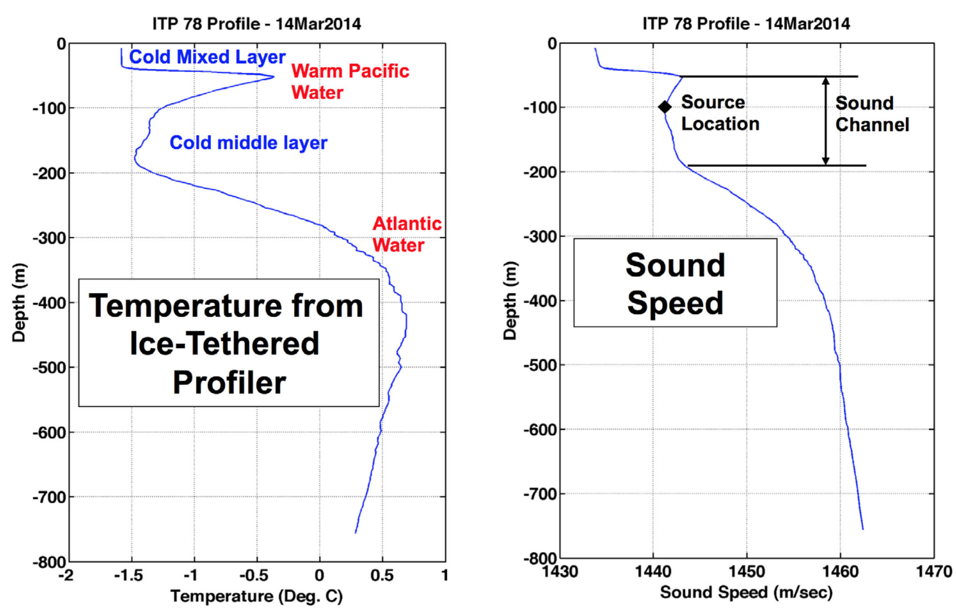

Figure 4. Temperature and sound speed profile from an Ice Tethered Profiler near one of the navigation buoys.

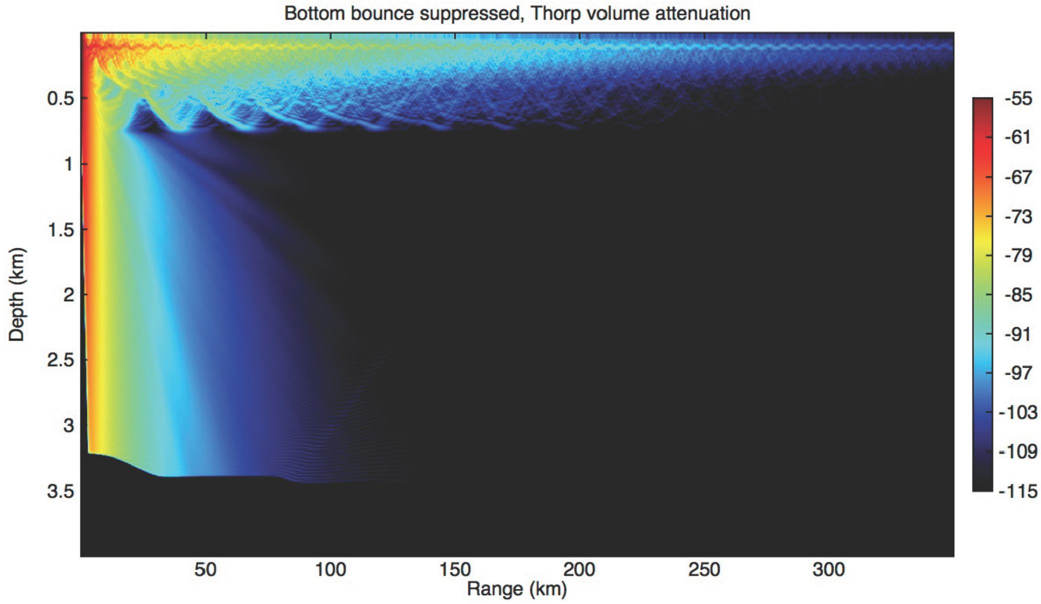

Figure 5. Transmission loss modeled from the ITP sound-speed profile showing the duct at 100 m.

Receiver Performance, Range. The receivers on each of the buoys are enabled during the entire period when they transmit, and thus we were able to monitor the performance of the system as soon as the network was deployed in late March, 2014. While the original plan for positioning was based on maximum ranges of approximately 100 km, it soon became clear that the system was operating at three times that estimate. The WHOI ice-tethered profilers that were deployed at the same time showed the reason: a strong duct was present between 50 and 250 meters due to warm Pacific water (at 50 m), and warm Atlantic water below (Figure 4). The upper layer of the duct prevents the signal from interacting with the ice, where it would scatter, and the lower layer refracts the signal back into the duct without loss as well. Figure 5 shows the transmission loss with respect to range for a source at 100 m. The sound is trapped in the duct and propagates for hundreds of kilometers. Ranges of 200 to 300 km were typical, and ranges of 400 to 500 km were sometimes observed between specific pairs of buoys.

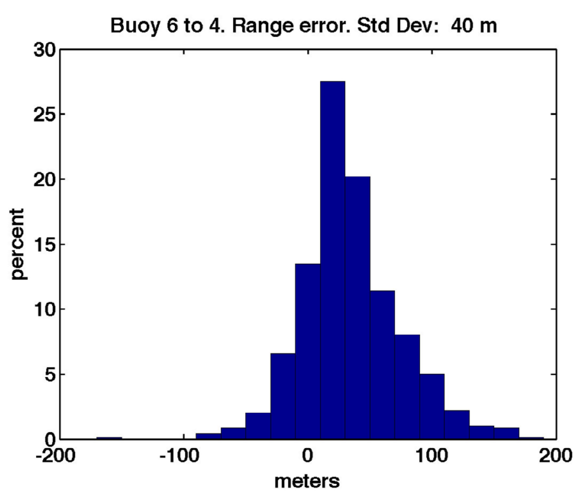

Figure 6. Buoy to buoy travel time error for ranges of 200-250 km.

Receiver Performance, Travel Time. The performance of the system in terms of navigation error may be calculated by comparing the GPS-derived range with the measured travel time. To make an estimate of the best-case error the sound-speed is estimated such that the range mean is near zero, which is the case where sound-speed is perfectly known. The range error histogram is shown in Figure 6, and the standard deviation is 40 m for this data set taken over several weeks at ranges that varied between 200 and 250 km. The original goal was approximately 1 km, but the measured performance was about five times better, most likely because there is very little time-spread in the propagation of the wavefront through the shallow duct.

Beacon-to-Seaglider Performance. While the beacon-to-beacon transmissions were made in the duct, the Seagliders, by nature of their propulsion method that requires vertical motion, were not frequently in the duct during a transmission interval. Thus the performance of the receivers mounted on the Seagliders is not nearly as good as on the beacons. However, the following observations may be made:

1. For ranges less than approximately 100 km the Seagliders heard the beacons and typically half the time successfully decoded the source position data transmitted with it.
2. From 100 to 300 km when receptions occurred between the surface and 200 m depth the majority of the detections resulted in good source locations.
3. From 300 to 450 km the receptions with travel times that were deemed correct based on their arrival time did not often have good position data because it did not decode correctly.

The reasons for the difference in performance are most likely due to propagation conditions in and out of the duct. Receivers in the duct hear the source at any range, while those outside the duct are in a range-dependent environment where signals come and go depending on the pattern of refraction at the lower turning points.

IMPACT/APPLICATIONS

The potential impact of this project is that it allows a drifting, ice-tethered navigation and communications system to be employed in the Arctic during times when it is not possible for UUVs to safely surface.

TRANSITIONS

While no transitions are currently planned, clearly the technology is applicable to Navy UUVs performing tactical missions under Arctic ice. Potential programs for transition include LD-UUV if an Arctic version is fielded in the future.

RELATED PROJECTS

WHOI is working with a small business, OASIS (Lexington, MA) on an ONR STTR focused on acoustic modeling and system design for a next generation of long-range acoustic navigation and communications. PI: Kevin Heaney (OASIS). Grant Number: N00014-12-M-0353. ONR Program Manager: Scott Harper.

PUBLICATIONS

Freitag, L., P. Koski, A. Morozov, S. Singh, J. Partan, "Acoustic Communications and Navigation Under Arctic Ice", *OCEANS, 2012 MTS/IEEE Conference*, Hampton Roads, VA, October 2012.

Freitag, L. E., K. Ball, S. Singh, P. Koski, J. Partan, and A. Morozov. "Technology for Real-Time Acoustic Communications and Navigation Under Arctic Sea Ice." *In AGU Fall Meeting Abstracts*, vol. 1, p. 0685. 2013. Abstract #C13C-0685.